



Individual calibration of accelerometers in children and their health-related implications

Boddy, L. M., Cunningham, C., Fairclough, S. J., Murphy, M. H., Breslin, G., Foweather, L., Dagger, R. M., Graves, L. E. F., Hopkins, N. D., & Stratton, G. (2018). Individual calibration of accelerometers in children and their health-related implications. *Journal of Sports Sciences*, 36(12), 1340-1345.
<https://doi.org/10.1080/02640414.2017.1377842>

[Link to publication record in Ulster University Research Portal](#)

Published in:
Journal of Sports Sciences

Publication Status:
Published (in print/issue): 30/06/2018

DOI:
[10.1080/02640414.2017.1377842](https://doi.org/10.1080/02640414.2017.1377842)

Document Version
Author Accepted version

General rights
Copyright for the publications made accessible via Ulster University's Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
The Research Portal is Ulster University's institutional repository that provides access to Ulster's research outputs. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact pure-support@ulster.ac.uk.

Title Page

Title: Individual calibration of accelerometers in children and their health-related implications

Running Title: Individual PA calibration and health implications

Keywords: physical activity, accelerometry, threshold, children

Authors: Lynne M. Boddy¹, L.M.Boddy@ljmu.ac.uk **
Conor Cunningham², Cunningham-C15@email.ulster.ac.uk
Stuart J. Fairclough^{3, 4}, Stuart.Fairclough@edgehill.ac.uk
Marie H. Murphy², mh.murphy@ulster.ac.uk
Gavin Breslin², g.breslin1@ulster.ac.uk
Lawrence Foweather³, L.Foweather@ljmu.ac.uk
Rebecca M. Dagger⁵, Daggerb@hope.ac.uk
Lee E.F. Graves¹, L.E.Graves@ljmu.ac.uk
Nicola D. Hopkins¹, N.D.Hopkins@ljmu.ac.uk
Gareth Stratton^{6,7}, G.Stratton@swansea.ac.uk

1. The Physical Activity Exchange, Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, 62 Great Crosshall Street, Liverpool, L3 2AT.
2. Sport and Exercise Sciences Research Institute, Ulster Sports Academy, University of Ulster, Jordanstown Campus, Shore Road, Newtownabbey, Co. Antrim, BT37 0QB, UK.
- 3 Department of Sport and Physical Activity, Edge Hill University, St Helens Road, Ormskirk, L39 4QP
4. Department of Physical Education and Sport Sciences, University of Limerick, Limerick, Ireland
5. Department of Health Sciences, Liverpool Hope University, Hope Park, Liverpool, L16 9JD, UK.
6. Applied Sports Technology, Exercise and Medicine Research Centre, College of Engineering, Swansea University, Bay Campus Fabian Way Swansea SA1 8EN
7. School of Sports Science, Exercise and Health, the University of Western Australia, Perth, Australia.

** Corresponding Author: Dr. Lynne M. Boddy,
The Physical Activity Exchange,
Research Institute for Sport and Exercise Sciences,
Liverpool John Moores University,
62 Great Crosshall Street,
Liverpool,
L3 2AT
Email: L.M.Boddy@ljmu.ac.uk
Tel: 0151 231 4275

Abbreviated Title: Children's Activity-health associations using different intensity cutpoints

Article Type: Original research article

Author Contributions: Contributors: LMB; analysed the data. LMB, CC, GS and SJF; wrote this manuscript. LMB and GS; designed and conceived the REACH Y6 study. LMB, LF, RG, LEFG and NDH: acquisition and analysis of REACH Y6 data in Liverpool, MHM, CC, GB;

50 acquisition and analysis of data in Ulster. GS, MHM, SJF, CC; substantial contribution to
51 writing and critical review of the article. All authors approved the article prior to submission.

52
53 **Funding:** This study was funded by Liverpool John Moores University and by the University
54 of Ulster.

55
56
57 **Disclosure:** There are no conflicts of interest for this study.

58
59 **Author declaration:** This study has not been published elsewhere and is not being considered
60 for publication elsewhere.

61
62
63 ***Acknowledgments***

64 We would like to thank the participants, parents, schools and researchers involved in the
65 REACH Y6 study. We would also like to thank Nicola Lyons, Dr Paul Newland, Dr Jeff Jones
66 and Dr Marcus Auth for Alder Hey Children's NHS Foundation Trust for their key input in
67 arranging phlebotomy and biochemical analysis and Dr Giles Aldworth from the Ulster
68 Hospital for his involvement in this study. We would also like to acknowledge the contribution
69 of Professor Non Thomas who passed away in 2012 for her expert advice and support when
70 setting up this project. This study was funded by Liverpool John Moores University and Ulster
71 University.

72 **Abstract**

73 This study compared children's physical activity (PA) levels, the prevalence of children
74 meeting current guidelines of ≥ 60 minutes of daily moderate to vigorous PA (MVPA), and
75 PA-health associations using individually calibrated (IC) and empirical accelerometer
76 cutpoints. Data from 75 (n = 32 boys) 10-12 year old children were included in this study.
77 Clustered cardiometabolic (CM) risk, directly measured cardiorespiratory fitness (CRF),
78 anthropometric and 7 day accelerometer data were included within analysis. PA data were
79 classified using Froude anchored IC, Evenson et al., 2008 (Ev) and Mackintosh et al., 2012
80 (Mack) cutpoints. The proportion of the cohort meeting ≥ 60 mins MVPA/day ranged from
81 37%-56% depending on the cutpoints used. Reported PA differed significantly across the
82 cutpoint sets. IC LPA and MPA were predictors of CRF (LPA: standardised $\beta = 0.32$, $p =$
83 0.002 , MPA: standardised $\beta = 0.27$ $p = 0.013$). IC MPA also predicted BMI Z-score
84 (standardised $\beta = -0.35$, $p = 0.004$). Ev VPA was a predictor of BMI Z-score (standardised β
85 $= -0.33$, $p = 0.012$). Cutpoint choice has a substantial impact on reported PA levels though no
86 significant associations with CM risk were observed. Froude IC cut points represent a
87 promising approach towards classifying children's PA data.

88 **Introduction**

89 Regular participation in physical activity (PA) in childhood is associated with reduced
90 cardiometabolic risk (Andersen, Riddoch, Kriemler, & Hills, 2011), improved bone health
91 (Boreham & McKay, 2011), reduced adiposity (McMurray & Ondrak, 2013), and improved
92 psychological well-being (Biddle & Asare, 2011). PA guidelines state that children should
93 accrue at least 60 minutes of daily moderate to vigorous PA (MVPA) to receive health benefits
94 (WHO, 2010). The accurate measurement of PA is essential to investigate the associations
95 between PA and health, estimate the prevalence of inactivity, and identify children in need of
96 intervention. Accelerometry is the most commonly used objective method for assessing free-
97 living PA in children, and has acceptable validity and reliability (Cain, Sallis, Conway, Van
98 Dyck, & Calhoun, 2013). Despite this, no consensus exists with regards to the treatment of
99 accelerometer data and inconsistent use of cutpoints presents challenges when quantifying the
100 prevalence of inactivity (Ekelund, Tomkinson, & Armstrong, 2011), making comparisons
101 between studies (Hislop, Bulley, Mercer, & Reilly, 2012) and establishing the relationship
102 between PA and health outcomes (Bailey, Boddy, Savory, Denton, & Kerr, 2013).

103

104 Previous research has compared the classification accuracy of published thresholds (PTs) in
105 youth using calibration studies, and recommended that researchers use Evenson's (Evenson,
106 Catellier, Gill, Ondrak, & McMurray, 2008) cutpoints to classify children's PA (Trost,
107 Loprinzi, Moore, & Pfeiffer, 2011). However, the empirical cutpoints examined by Trost et
108 al. (2011) applied universal cutpoints to all children, with only one age-specific cutpoint
109 included in the analysis (Freedson, Pober, & Janz, 2005). Such cutpoints fail to account for
110 wide variations in accelerometer counts observed between children when engaging in PA at
111 equivalent intensities (Rowlands, 2007). Subsequently researchers have proposed the use of
112 individually calibrated (IC) approaches to improve the classification of children's PA
113 (Mackintosh, Fairclough, Stratton, & Ridgers, 2012).

114

One method of deriving individual cutpoints, particularly when using hip-mounted accelerometers, is to adjust cutpoints to account for limb length using relevant biomechanical theory. The Froude (Fr) number (Minetti, 2001) offers one solution to the standardisation of cutpoints for individuals, by taking the length of a given characteristic, in this case leg length, into account. Froude numbers are calculated using the equation: $Fr = v^2/g \cdot l$ where 'v' is the speed, 'g' represents gravitational acceleration and 'l' is the length of the characteristic. The theory of dynamic similarity suggests that geometrical bodies have similar gait dynamics if the Fr number is kept constant (Alexander, 1989). For example, the Fr number of 0.25 represents optimum walking speed and Fr 0.5 is the point at which running occurs in most bipedal bodies, including humans (Kram, Domingo, & Ferris, 1997). Therefore for a given Fr number and related walking speed gait dynamics should be relatively consistent between participants, which in turn allows for a simple method of creating individualised and comparable thresholds. Despite its potential utility, few studies have utilised the Froude approach to individually calibrate accelerometer cutpoints (Boddy et al., 2014). As PA is positively associated with health, the potential to better examine these relationships with more precise estimates of PA is important, especially as relationships between PA and variables such as CRF and adiposity are often weaker than may be expected. To date no have examined differences in reported PA or PA-health associations between IC and empirically derived group level cutpoints. Therefore, the aims of this study were to compare children's physical activity (PA) levels, the prevalence of children meeting current guidelines of 60 minutes of daily moderate to vigorous PA (MVPA), and PA-health associations using individually calibrated Fr (IC) and empirical accelerometer cutpoints.

137

138 **Methods**

139 *Participants and Settings*

The data for this analysis were taken from the REACH Year 6 study (Boddy et al., 2014). Seventy-five children (n = 32 boys) 10-12 years of age agreed to take part in the study which had ethical clearance from the respective institutional ethics committees. The study was

143 conducted in Liverpool, England (2010, n = 39) and Belfast, Northern Ireland (2011, n = 35).
144 Each participant attended one school-based blood sampling session and one laboratory testing
145 session. Participants also wore an accelerometer to quantify PA over seven days.

146

147

148 *Procedure and Measurements*

149 Anthropometrics: Stature, sitting stature to the nearest 0.1cm (Seca Ltd. Birmingham, UK)
150 and body mass to the nearest 0.1kg (Seca Ltd. Birmingham, UK) were assessed using standard
151 techniques (Lohman, Roche, & Martorell, 1988). Waist circumference was measured to the
152 nearest 0.1cm. Body mass index (BMI), BMI Z-scores (Cole, Freeman, & Preece, 1995) and
153 somatic maturation (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002) were calculated. High-
154 resolution ultrasound (Terason, t3000; Aloka, London, UK) was used to assess flow mediated
155 dilation (FMD) and % FMD calculated using the equation: $((\text{Peak artery diameter} - \text{Baseline}$
156 $\text{artery diameter}) / \text{Baseline artery diameter}) * 100$ was calculated. Blood pressure (BP) was
157 measured on the left arm after 15mins rest in a supine position using an automated BP monitor
158 (Omron Healthcare UK Limited, Miton Keynes, UK).

159

160 Cardiorespiratory fitness assessment: After treadmill familiarisation, participants completed
161 an individually calibrated continuous, incremental (2mins stages) treadmill (both sites: HP
162 Cosmos, Traunstein, Germany) protocol to volitional exhaustion using online gas analysis
163 (Liverpool: Jaeger Oxycon Pro, Viasys Health Care, UK, Ulster: COSMED, Quark, Italy) to
164 measure peak oxygen uptake ($\text{VO}_{2\text{peak}}$). Treadmill speeds for the first two stages of the test
165 were anchored to Froude numbers 0.25 (MPA) and 0.5 (VPA) for each participant. For this
166 study leg length was used as the characteristic. An example equation to calculate treadmill
167 speed for an individual with a leg length of 0.67m for a Fr number of 0.25 would be: treadmill
168 $\text{speed (m/s)} = \sqrt{(0.25 * (9.81 * 0.67))}$, which would result in a speed of 1.28 m/s or 4.61 km/h.
169 Participants wore an ActiGraph accelerometer (ActiGraph GT1M, MTI Health Services,
170 Pensacola, FL) at the right hip and heart rate monitor (Polar Electro Oy, Kempele, Finland)

171 set to record using 5 second epochs throughout the treadmill protocol. The highest 15-second
172 average oxygen uptake was used to represent $\text{VO}_{2\text{peak}}$ (ml/kg/min) for each participant.

173

174 Blood sampling: On a different day to the laboratory visits, children attended their school sites
175 to provide a fasting venous blood sample. Experienced phlebotomists obtained ~ 10ml of
176 venous blood following an overnight fast. Samples were taken between 8.30 and 10.30am.
177 After providing a sample children were given breakfast. Blood samples were transported to
178 the pathology laboratories at Alder Hey Children's Foundation NHS Trust or the Ulster
179 Hospital for analysis. Blood was analysed for triglycerides, cholesterol, high density
180 lipoprotein cholesterol (HDL-c), glucose, adiponectin, and high sensitivity C-reactive protein
181 (CRP) using assay methods that were standardised between sites. Blood markers were used in
182 combination with FMD%, blood pressure and waist circumference to calculate a clustered
183 cardiometabolic risk score by standardising individual risk components and summing them to
184 create a continuous clustered risk variable. This approach has been used in several similar
185 studies (Andersen, Hasselstrom, Gronfeldt, Hansen, & Karsten, 2004; Anderssen et al., 2007;
186 Boddy et al., 2014; Buchan, Young, Boddy, & Baker, 2014).

187

188 Physical activity assessment: Children wore an ActiGraph (ActiGraph GT1M) uniaxial
189 accelerometer on their right hip during waking hours for seven consecutive days. The monitors
190 recorded activity using 5 second epochs to account for the sporadic nature of children's
191 physical activity (Baquet, Stratton, Van Praagh, & Berthoin, 2007). Periods of 20 minutes of
192 consecutive zero counts (1 minute spike tolerance) were used to define a non-wear period and
193 these periods were subtracted from daily wear time (Catellier et al., 2005). Children were
194 included within analysis if they wore the monitor for a minimum of 9 hrs on any three days
195 (Mattocks et al., 2008).

196 PA data were classified into light (LPA), moderate (MPA), vigorous (VPA) and moderate to
197 vigorous PA (MVPA) intensities using three sets of intensity cutpoints: two sets of empirical
198 cutpoints: Evenson et al., 2008 (Ev) and Mackintosh et al., 2012 (Mack). The Mack

thresholds were generated from data derived from a field-based observational protocol with children of the same age and from a similar geographical location as those included within this study and were included to provide an additional comparison. PA was also classified using individually calibrated (IC) cut points. Sedentary time was defined as ≤ 100 counts per minute for all cut point sets (Fischer, Yildirim, Salmon, & Chinapaw, 2012). Individually calibrated cut points were generated using the data from the VO_2 peak treadmill protocol. Froude 0.25 and 0.50 represent the thresholds for optimum walking speed and the transition between walking and running. The average counts for the middle 90 seconds (18 epochs) of the two Fr stages (Fr 0.25 and Fr 0.50) were used to represent MPA and VPA thresholds for each individual. The middle 90 seconds were selected to avoid the transitional periods between the Fr.25 (walking) and Fr.5 (running). To examine the energy cost associated with each Fr threshold metabolic equivalents were calculated for Fr.25 and Fr.5 stages using the gas analysis data ($1 \text{ MET} = 4.59 \text{ } VO_2 \text{ ml/kg/min}$; (Ridley & Olds, 2008) and compared to the energy costs outlined by Harrell et al. (2005). This gas analysis data was simply used to assess the MET values associated with the Fr stages for each individual.

214

215 *Data analysis*

Differences in anthropometrics, clustered risk, VO_2 peak, sedentary time and PA components (MPA, VPA, MVPA) were examined by sex using MANCOVA, controlling for accelerometer wear time. The prevalence of those reaching ≥ 60 mins MVPA per day was calculated for each cutpoint set. Differences in PA intensities were examined using repeated measures ANOVAs by cutpoint. To investigate the association between PA components and health markers (VO_2 peak, BMI Z-score, waist circumference, clustered cardiometabolic risk) multiple regression was employed controlling for sex, maturation, BMI and wear time. For each dependent variable three multiple regression models, one for each cutpoint, were created. Where BMI was used as a dependent variable it was excluded as a covariate. All analyses were completed using SPSS V21.0 (SPSS Inc, IBM). Alpha was set at $P \leq 0.05$.

226 **Results**

227 Unadjusted mean participant characteristics and adjusted mean anthropometric, VO_2peak ,
228 sedentary time and PA values for boys and girls are illustrated in tables 1 and 2 respectively.
229 Boys were significantly less mature, had higher VO_2peak and accrued more LPA and MPA
230 than girls.

231

232 TABLE 1 ABOUT HERE

233 TABLE 2 ABOUT HERE

234

235 The IC cut points ranged from 1234-4476 counts per minute for MPA and 3192-9357 counts
236 per minute for VPA. The mean oxygen consumption ($\text{VO}_2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and MET values (1
237 $\text{MET} = 4.59 \text{ VO}_2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) achieved during the treadmill stages Fr0.25 and Fr.5 were
238 $20.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ($\text{SD} = 4.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), 4.4 METs and $31.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ($\text{SD} = 7.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)
239 6.8 METs respectively. These values are proximal to those commonly used to
240 represent MPA ($\geq 4 \text{ METs}^+$) and VPA ($\geq 6 \text{ METs}$) in the PA literature. Data from Harrell et
241 al (2005) calculated for children aged 8-12 years confirm that participants were working at an
242 intensity approximately equivalent to moderate intensity during Fr 0.25 (Harrell et al. (2005)
243 values: $\text{VO}_2 = 18.3 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and approaching high intensity activity during Fr 0.50
244 (Harrell et al. (2005) values: $\text{VO}_2 = 38.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$).

245

246 The proportion of children meeting $\geq 60\text{mins/day}$ MVPA varied depending on the cutpoints
247 used. According to the Mack cutpoints 56% met $\geq 60\text{mins/day}$ MVPA, whereas 49% and 37%
248 achieved 60mins according to Ev and IC cutpoints respectively.

249 The results of the repeated measures ANOVAs between cutpoint sets can be viewed in Table
250 3. Significantly higher MPA was reported using the Mack ($\text{MPA} = 51.6 \text{ mins/day}$) cutpoints
251 in comparison to the Ev ($\text{MPA} = 38.4 \text{ mins/day}$) and IC cutpoints ($\text{MPA} = 44.3 \text{ mins/day}$). Ev
252 cutpoints ($\text{VPA} = 25.9 \text{ mins/day}$) recorded higher VPA than Mack (17.8 mins/day) and IC

(13.0 mins/day). Significantly less LPA was observed using the Mack (195 mins/day) cutpoints in comparison to IC (209 mins/day) and Ev (200.3 mins/day), the difference between IC and Ev LPA was also statistically significant.

TABLE 3 ABOUT HERE

Results of multiple regression found that IC LPA and MPA were significant predictors of VO_2 peak (R^2 for the model = 0.55, LPA: standardised beta = 0.32, $t = 3.24$, $p = 0.002$, MPA: standardized beta = 0.27, $t = 2.57$, $p = 0.013$) IC MPA was also a significant predictor for BMI Z-score (R^2 for the model = 0.31, standardised beta = -0.35, $t = -2.96$, $p = 0.004$). Ev VPA was a significant predictor for BMI Z-score (R^2 for the model = 0.32, standardized beta = -0.33, $t = -2.59$, $p = 0.012$), Mack data were not significant predictors for any health variables, however Mack VPA approached statistical significance as a predictor for BMI Z-score (R^2 for the model = 0.29, VPA standardized beta = -0.23, $t = -1.98$, $p = 0.052$). No significant PA-clustered risk score associations were observed irrespective of cut point set used.

Discussion

The aims of this study were to compare children's physical activity (PA) levels, the prevalence of children meeting current guidelines of 60 minutes of daily moderate to vigorous PA (MVPA), and PA-health associations using individually calibrated Fr (IC) and empirical accelerometer cutpoints. In this study the proportion of the cohort meeting current guidelines for daily MVPA ranged from 37% - 56% depending upon the cut point used. A number of studies have shown differences in PA prevalence depending on the choice of cut points used to analyse data (Hislop et al., 2012; Reilly et al., 2008). For example, a review by Ekelund et al. (2011) highlighted that the reported prevalence of children and young people meeting current PA guidelines ranged across six studies from 1% and 100%, with authors suggesting that the variability could be largely attributed to the different intensity cutpoints used between studies. At a 4 MET intensity (approximate to MPA) recommended counts per minute have

281 ranged widely from 1400 to 3600 (Cain et al., 2013). In this study, IC cut points derived from
282 the treadmill-based protocol ranged from 1234-4476 for MPA, with a mean MET value of 4.4
283 (range 2.49-7.04 METs) and 3192-9357 for VPA (mean MET value of 6.8, range 3.83-12.33
284 METs). This demonstrates the substantial variation that exists in the biomechanical efficiency
285 of movement (e.g. stride length, stride pattern) between children of a similar age completing
286 the same activity, and provides support for the use of IC cut points that take account of
287 individual differences.

288

289 This study also revealed significant differences in the classification of LPA, MPA and VPA
290 depending upon the cutpoint used. The discrepancies in the classification of PA intensities
291 observed may be in part due to the differing methods used to define each of the cutpoint
292 thresholds. For example, the IC cut points used in this study were derived from the application
293 of biomechanical theory, which is in contrast to the empirical cut points derived from
294 laboratory based (Ev) or field-based (Mack) energy expenditure. Although it is well
295 documented that the application of different cut points results in differences in estimates of
296 activity intensity (Trost et al., 2011), to date, none of the published papers have compared the
297 classification of activity intensity between IC and empirical cut points. Our findings suggest
298 that researchers should be cautious about the universal application of cut points which fail to
299 account for individual differences between participants, particularly with evidence suggesting
300 wide variations in step counts between children when engaging in PA at equivalent intensities
301 (Rowlands, 2007). The application of more specific cutpoints may provide an opportunity to
302 reduce sample size requirements within studies due to better estimates of primary outcome
303 measures.

304

305 Despite calls for raw data processing techniques to remove the reliance on proprietary counts
306 based data, this approach still requires the use of cutpoints or acceleration thresholds to
307 classify raw acceleration signals, therefore the findings of this study apply in the raw data
308 analysis context. To remove the requirement of cutpoints, pattern recognition or machine

learning approaches to classify accelerometer data have been proposed Despite the potential utility of this approach the majority of PA research conducted to date using accelerometers still utilises proprietary counts data and apply group level thresholds to the data, therefore the IC approach proposed within this paper is recommended. The range in prevalence and classification of PA resulting from the application of different cut points underscores the need for a consensus on accelerometer thresholds to quantify PA intensity. The array of thresholds used by researchers makes comparison between studies problematic, leading to conflicting conclusions (Hislop et al., 2012). The inconsistent use of these thresholds is also a major issue when attempting to quantify the prevalence of inactivity (Ekelund et al., 2011), has impacted upon PA policy making for children (Bailey et al., 2013) and the relationships between PA and health outcomes (Bailey et al., 2013). For example, in their comparison of three published thresholds (Chu, McManus, & Yu, 2007; Rowlands, Thomas, Eston, & Topping, 2004; Vanhelst et al., 2010) Bailey et al. (2013) reported a range of different associations between PA and health outcomes such as blood pressure, waist circumference, cardiorespiratory fitness and metabolic markers such as glucose and triglycerides. In our study, although the estimates of the intensity of PA differed according to thresholds used, relationships detected with the clustered cardiometabolic risk score were consistent. However, the IC cut points had the strongest associations with VO_{2peak} , an important independent predictor of cardiometabolic risk (Andersen et al., 2011). This may be due to the methods utilised to create the IC cutpoints and the treadmill-based VO_{2peak} protocol. Whether the approach of individually calibrating PA thresholds according to limb length is as effective at predicting energy expenditure across a range of different activities warrants further investigation. Furthermore, the empirical cutpoints used in this study were created using field-based protocols that included a range of typical daily activities. The differences described between these methods and the IC approach may relate to the protocols used to generate the cutpoints, rather than the accuracy of the cutpoints per se.

336 When compared to the use of a portable metabolic unit (Ev) or PA observation (Mack), it
337 appears that the treadmill-based calibration protocol used in this study was more effective in
338 accounting for individual differences in biomechanical efficiency of movement (e.g limb
339 length, stride length/frequency) by matching the accelerometer counts to changes in speed and
340 resulting PA intensity. Whereas in previous research, the observed relationships between CRF
341 and PA in children have been weaker than expected, for example weak-moderate standardized
342 regression coefficients (0.14-0.33) between aerobic fitness and PA have been
343 reported (Kristensen et al., 2010), the present findings suggest that IC cut points highlight
344 stronger associations between children's PA and CRF than are often reported. Moreover, there
345 is a growing body of evidence that links CRF to cardiometabolic disease risk in children
346 (Anderssen et al., 2007) (Boddy et al., 2014). Therefore, our findings have important
347 implications for researchers investigating the associations between activity status, CRF and
348 health, and practitioners referring inactive individuals for lifestyle intervention.

349

350 Strengths and Limitations: This is the first study to examine differences in reported PA, and
351 PA-health relationships between Fr IC and empirically derived cut points. The generic
352 cutpoint method is less time consuming than completing laboratory calibration studies
353 involving multiple activities and portable calorimetry or observation. Despite this, the
354 individual calibration approach used within this study does not take into account movement
355 patterns other than walking and running, and although the majority of children's activity is
356 ambulatory the method may not accurately classify other types of movements completed by
357 children. The method also did not merge the VO_2 data from the fitness assessment that would
358 have provided energy expenditure data. This was purposeful to allow the examination of the
359 thresholds based on the Fr number alone, rather than a more complex hybrid threshold
360 approach. An evolution of this method could be proposed that utilises VO_2 data to examine
361 whether the precision of the thresholds is improved, however this was beyond the scope and
362 aims of the current study. In addition, the Fr number could result in non-ecological walking
363 patterns which are not representative of 'usual' walking speeds. It is important to note that

364 maturational factors may influence metabolic efficiency and therefore energy expenditure
365 within this population. The influence of maturation on energy expenditure was not explored
366 within this study, mainly because of the repeated measures nature of the analysis when
367 comparing thresholds, however warrants consideration when working with populations within
368 this age range. This study used a range of established and emerging risk factors to provide a
369 robust estimate of cardiometabolic risk. However, the participants involved in this study were
370 healthy children, which may account for the lack of associations observed between the PA
371 data and cardiometabolic risk scores. Stronger PA-health associations may be apparent in a
372 population exhibiting greater cardiometabolic risk. The treadmill measure of VO_2peak is
373 considered the reference standard, though standardised protocols were used, data were taken
374 using different gas analysis systems in Liverpool and Ulster (Oxycon Pro and COSMED)
375 which may influence comparability between the VO_2peak estimates.

376

377 *Conclusion*

378 This study has demonstrated that the application of different intensity thresholds has an impact
379 when determining the proportion of children meeting current daily PA guidelines. To make
380 accurate evidence based recommendations, a consensus on appropriate accelerometer
381 thresholds for quantifying PA intensity is needed. IC cut points provide evidence of a stronger
382 association between children's PA and CRF than is often reported. This finding has important
383 implications for researchers and practitioners investigating the associations between activity
384 status, CRF and health and referring inactive individuals for lifestyle intervention. Additional
385 research is needed with larger cohorts to fully examine the potential of using IC cut points to
386 classify children's PA.

387

388 **References**

- 389 Alexander, R. M. (1989). Optimization and gaits in the locomotion of vertebrates. *Physiol*
390 *Rev*, 69(4), 1199-1227
- 391 Andersen, L. B., Hasselstrom, H., Gronfeldt, V., Hansen, S. E., & Karsten, F. (2004). The
392 relationship between physical fitness and clustered risk, and tracking of clustered
393 risk from adolescence to young adulthood: eight years follow-up in the Danish
394 Youth and Sport Study. *Int J Behav Nutr Phys Act*, 1(1), 6
- 395 Andersen, L. B., Riddoch, C., Kriemler, S., & Hills, A. P. (2011). Physical activity and
396 cardiovascular risk factors in children. *Br J Sports Med*, 45(11), 871-876. doi:
397 10.1136/bjsports-2011-090333
- 398 Anderssen, S. A., Cooper, A. R., Riddoch, C., Sardinha, L. B., Harro, M., Brage, S., &
399 Andersen, L. B. (2007). Low cardiorespiratory fitness is a strong predictor for
400 clustering of cardiovascular disease risk factors in children independent of country,
401 age and sex. *Eur J Cardiovasc Prev Rehabil*, 14(4), 526-531. doi:
402 10.1097/HJR.0b013e328011efc1
- 403 Bailey, D. P., Boddy, L. M., Savory, L. A., Denton, S. J., & Kerr, C. J. (2013). Choice of activity-
404 intensity classification thresholds impacts upon accelerometer-assessed physical
405 activity-health relationships in children. *PLoS One*, 8(2), e57101. doi:
406 10.1371/journal.pone.0057101
- 407 Baquet, G., Stratton, G., Van Praagh, E., & Berthoin, S. (2007). Improving physical activity
408 assessment in prepubertal children with high-frequency accelerometry monitoring:
409 a methodological issue. *Prev Med*, 44(2), 143-147. doi:
410 10.1016/j.ypmed.2006.10.004
- 411 Biddle, S. J., & Asare, M. (2011). Physical activity and mental health in children and
412 adolescents: a review of reviews. *Br J Sports Med*, 45(11), 886-895. doi:
413 10.1136/bjsports-2011-090185
- 414 Boddy, L. M., Murphy, M. H., Cunningham, C., Breslin, G., Foweather, L., Gobbi, R., . . .
415 Stratton, G. (2014). Physical activity, cardiorespiratory fitness, and clustered
416 cardiometabolic risk in 10- to 12-year-old school children: The REACH Y6 study. *Am*
417 *J Hum Biol*, 26(4), 446-451. doi: 10.1002/ajhb.22537
- 418 Boreham, C. A., & McKay, H. A. (2011). Physical activity in childhood and bone health. *Br J*
419 *Sports Med*, 45(11), 877-879. doi: 10.1136/bjsports-2011-090188
- 420 Buchan, D. S., Young, J. D., Boddy, L. M., & Baker, J. S. (2014). Independent associations
421 between cardiorespiratory fitness, waist circumference, BMI, and clustered
422 cardiometabolic risk in adolescents. *Am J Hum Biol*, 26(1), 29-35. doi:
423 10.1002/ajhb.22466
- 424 Cain, K., Sallis, J. F., Conway, T. L., Van Dyck, D., & Calhoun, L. (2013). Using accelerometers
425 in youth physical activity studies: a review of methods. *Journal of Physical Activity*
426 *& Health*, 10, 437-450
- 427 Catellier, D. J., Hannan, P. J., Murray, D. M., Addy, C. L., Conway, T. L., Yang, S., & Rice, J. C.
428 (2005). Imputation of missing data when measuring activity by accelerometry. *Med*
429 *Sci Sports Exerc*, 37(Suppl 11), S555-S562
- 430 Chu, E. Y., McManus, A. M., & Yu, C. C. (2007). Calibration of the RT3 accelerometer for
431 ambulation and nonambulation in children. *Med Sci Sports Exerc*, 39(11), 2085-
432 2091. doi: 10.1249/mss.0b013e318148436c
- 433 Cole, T. J., Freeman, J. V., & Preece, M. A. (1995). Body mass index reference curves for the
434 UK, 1990. *Arch Dis Child*, 73(1), 25-29
- 435 Ekelund, U., Tomkinson, G., & Armstrong, N. (2011). What proportion of youth are
436 physically active? Measurement issues, levels and recent time trends. *Br J Sports*
437 *Med*, 45(11), 859-865. doi: 10.1136/bjsports-2011-090190

438 Evenson, K. R., Catellier, D. J., Gill, K., Ondrak, K. S., & McMurray, R. G. (2008). Calibration of
 439 two objective measures of physical activity for children. *J Sports Sci*, 26(14), 1557-
 440 1565. doi: 10.1080/02640410802334196

441 Fischer, C., Yildirim, M., Salmon, J., & Chinapaw, M. J. M. (2012). Comparing different
 442 accelerometer cut-points for sedentary time in children. *Pediatric Exercise Science*,
 443 24(2), 220-228

444 Freedson, P., Pober, D., & Janz, K. F. (2005). Calibration of accelerometer output for
 445 children. *Med Sci Sports Exerc*, 37(11 Suppl), S523-530

446 Harrell, J. S., McMurray, R. G., Baggett, C. D., Pennell, M. L., Pearce, P. F., & Bangdiwala, S. I.
 447 (2005). Energy costs of physical activities in children and adolescents. *Med Sci*
 448 *Sports Exerc*, 37(2), 329-336

449 Hislop, J., Bulley, C., Mercer, T., & Reilly, J. (2012). Comparison of accelerometry cut points
 450 for physical activity and sedentary behavior in preschool children: a validation
 451 study. *Pediatric Exercise Science*, 24(4), 563-576

452 Kram, R., Domingo, A., & Ferris, D. P. (1997). Effect of reduced gravity on the preferred
 453 walk-run transition speed. *J Exp Biol*, 200(Pt 4), 821-826

454 Kristensen, P. L., Moeller, N. C., Korsholm, L., Kolle, E., Wedderkopp, N., Froberg, K., &
 455 Andersen, L. B. (2010). The association between aerobic fitness and physical
 456 activity in children and adolescents: the European youth heart study. *Eur J Appl*
 457 *Physiol*, 110(2), 267-275. doi: 10.1007/s00421-010-1491-x

458 Lohman, T., Roche, A. F., & Martorell, R. (1988). *Anthropometric standardization reference*
 459 *manual*. Champaign, Illinois: Human Kinetics.

460 Mackintosh, K. A., Fairclough, S. J., Stratton, G., & Ridgers, N. D. (2012). A calibration
 461 protocol for population-specific accelerometer cut-points in children. *PLoS One*,
 462 7(5), e36919. doi: 10.1371/journal.pone.0036919

463 Mattocks, C., Ness, A., Leary, S., Tilling, K., Blair, S., Shield, J., . . . Riddoch, C. (2008). Use of
 464 accelerometers in a large field-based study of children: Protocols, design issues,
 465 and effects on precision. *Journal of Physical Activity & Health*, 5(S1), S98-S111

466 McMurray, R. G., & Ondrak, K. S. (2013). Cardiometabolic risk factors in children: The
 467 importance of physical activity. *American Journal of Lifestyle Medicine*, 7(5), 292-
 468 303

469 Minetti, A. E. (2001). Walking on other planets. *Nature*, 409(6819), 467-469

470 Mirwald, R., Baxter-Jones, A., Bailey, D., & Beunen, G. (2002). An assessment of maturity
 471 from anthropometric measurements. *Medicine & Science in Sports & Exercise*,
 472 34(4), 689-694

473 Reilly, J. J., Penpraze, V., Hislop, J., Davies, G., Grant, S., & Paton, J. (2008). Objective
 474 measurement of physical activity and sedentary behaviour: review with new data.
 475 *Arch Dis Child*, 93(7), 614-619

476 Ridley, K., & Olds, T. S. (2008). Assigning energy costs to activities in children: a review and
 477 synthesis. *Med Sci Sports Exerc*, 40(8), 1439-1446. doi:
 478 10.1249/MSS.0b013e31817279ef

479 Rowlands, A. V. (2007). Accelerometer assessment of physical activity in children: an
 480 update. *Pediatr Exerc Sci*, 19(3), 252-266

481 Rowlands, A. V., Thomas, P. W., Eston, R. G., & Topping, R. (2004). Validation of the RT3
 482 triaxial accelerometer for the assessment of physical activity. *Med Sci Sports Exerc*,
 483 36(3), 518-524

484 Trost, S. G., Loprinzi, P. D., Moore, R., & Pfeiffer, K. A. (2011). Comparison of accelerometer
 485 cut points for predicting activity intensity in youth. *Med Sci Sports Exerc*, 43(7),
 486 1360-1368. doi: 10.1249/MSS.0b013e318206476e

487 Vanhelst, J., Beghin, L., Rasoamanana, P., Theunynck, D., Meskini, T., Iliescu, C., . . .
 488 Gottrand, F. (2010). Calibration of the RT3 accelerometer for various patterns of

489 physical activity in children and adolescents. *J Sports Sci*, 28(4), 381-387. doi:
490 10.1080/02640410903508821
491 WHO. (2010). *Global Recommendations on Physical Activity for Health*. Geneva,
492 Switzerland.
493

494 Table 1. Raw mean [SE] participant characteristics by sex

Variable	Boys (n = 32)	Girls (n = 43)
Age (years)	10.47 [0.57]	10.5 [0.75]
Maturation offset (years)	-2.64 [0.71]	-0.95 [0.68]
BMI Z-score	0.65 [0.86]	0.53 [1.24]
Waist circumference (cm)	64.4 [6.4]	65.7 [9.57]
VO ₂ peak (ml/kg/min)	45.55 [9.71]	40.81 [8.7]
Diastolic BP (mmHg)	63 [6.2]	62.1 [6.7]
Systolic BP (mmHg)	103.6 [11.9]	102.3 [12.1]
FMD %	8.39 [3.24]	8.54 [4.26]
C-Reactive Protein (mg/L)	0.38 [0.29]	0.94 [1.32]
Triglycerides (mmol/L)	0.64 [0.2]	0.78 [0.28]
Cholesterol (mmol/L)	4.17 [0.67]	4.21 [0.54]
HDL-C (mmol/L)	1.59 [0.31]	1.49 [0.38]
Glucose (mmol/L)	4.71 [0.34]	4.63 [0.3]
Adiponectin (µg/mL)	10.58 [5.4]	11.14 [6.78]
Clustered CM risk	0.18 [4.01]	-0.38 [3.71]
Sedentary Time (mins/day)	440.4 [41]	458.8 [41.2]

IC LPA (mins/day)	220 [46]	200.7 [33]
IC MPA (mins/day)	52.4 [36.3]	38.3 [24.7]
IC VPA (mins/day)	14.2 [9.7]	12.2 [17.7]
IC MVPA (mins/day)	66.6 [37.5]	50.4 [31.9]
Accelerometer wear time (mins/day)	716.8 [49.2]	716.6 [116.9]

495

496 Table 2. Mean values [SE] for boys and girls adjusted for wear time (MANCOVA
 497 output, n = 61).

Variable	Boys	Girls	P value
Age (years)	10.45 [.13]	10.49 [.12]	.833
Maturation offset (years)	-2.63 [.14]	-0.89 [.13]	< 0.001
BMI Z-score	0.62 [.21]	0.70 [.18]	.776
Waist circumference (cm)	64.0 [1.6]	67.0 [1.5]	.173
VO₂peak (ml/kg/min)	46.39 [1.61]	39.28 [1.44]	.002
Clustered CM risk	-0.047 [.75]	-0.282 [.67]	.816
Sedentary Time (mins/day)	438.6 [7.7]	457.8 [6.9]	.069
IC LPA (mins/day)	221.5 [7.4]	196.3 [6.6]	.014
IC MPA (mins/day)	53.5 [5.9]	37.4 [5.3]	.047
IC VPA (mins/day)	14.0 [3.1]	12.6 [2.8]	.741
IC MVPA (mins/day)	67.5 [7.0]	50.1 [6.2]	.066

498

499

500 **Table 3. Adjusted mean [SE] physical activity across the three cutpoint sets**

Activity	Individually Calibrated		Mackintosh et al. 2012		Evenson et al., 2008	
Component	(IC) Minutes/day		(Mack) Minutes/day		(Ev) Minutes/day	
	Mean	SE	Mean	SE	Mean	SE
VPA	13.0 ^{*^}	1.7	17.8 [†]	1.7	25.9	2.0
MPA	44.3 ^{^^}	3.6	51.6 [^]	2.4	38.4	1.8
LPA	209.0 [‡]	4.1	195.0 [†]	3.7	200.3	3.8

501

502 ^{*}Ev > IC ($p < 0.001$), [†]Mack > IC ($p < 0.001$), [†]Ev > Mack ($p < 0.001$), ^{^^}Mack > IC

503 ($p = 0.005$) [^]Mack > Ev ($p < 0.001$), [‡]IC > Mack ($p < 0.01$) and IC > Ev ($p = 0.006$).

504